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POLARIZATION OF LASER RADIATION SCATTERED BY FOG AND SMOKE

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Questions of atmospheric optics, the visibility of polarized radiation sources in the atmosphere, light conditions in the depth of the scattering medium illuminated by polarized radiation, and other matters are linked with the need to investigate the polarization characteristics of scattered light. Similar investigations employing thermal sources were previously conducted by a number of authors [1-4] and it was shown that luminescence in the depth of a turbid medium depends both on the orientation of the polarization plane of the incident radiation and on the geometry of the optical diagram. The use of lasers with linear radiation polarization substantially increases the range of conditions in which the polarization characteristics of scattered light may be investigated. In particular, measurements are possible of the degree of polarization of scattered light at great optical depths as a result of the high energy density in the light beam from the laser.

~~Results of the~~ experimental investigations of the

degree of polarization of forward scattered and backward scattered (reflected) light during radiation discharge in artificial fog and smoke are described below.

EQUIPMENT AND PROCEDURES

The measurements were conducted in an artificial cloud chamber 35 m^3 in size. The optical diagram for the experiment is shown in Figure 1. The linear polarized radiation flux from the gas laser in a He - Ne mixture with wavelength $\lambda = 0.63$ mkm was directed at a chamber containing the scattering medium. The diameter of the light beam at the generator outlet was 4 mm and the divergence angle $\alpha = 6'$. The receiver was placed next to the source to measure the polarization characteristics of radiation scattered at an angle of $\beta = 172^\circ$ relative to the direction of distribution of laser irradiation. Registration of forward scattered radiation at small angles ($\beta = 1^\circ 30'$) was obtained with the same receiving equipment, but the radiation source was placed at the opposite side of the chamber.

The receiving system consisted of a lens with focal length of f = 1,600 mm and relative aperture of 1:10, the focal plane of which contained an aperture diaphragm with angular radius of 27', polaroid film (analyzer) and a photomultiplier. Changes in the angle ϕ between the plane

of incident radiation on the medium and the direction of the light vector E was achieved by turning the laser resonator relative to its axis. A more detailed description of this equipment has been provided in [5, 7, 10]. The optical and microphysical characteristics of artificial fog (parameter Mi $\rho = 60 \pm 20$) and of smoke ($\rho = 7 \pm 3$) are described in [5-7].

The measurement method was based on the fact that the degree of polarization of radiation is defined by the expression [8]

$$P = \frac{1-\Delta}{1+\Delta}; \tag{1}$$

where Δ is the depolarization equal to the ratio of light intensity I_1 with vector E, lying in the scattering plane, to the intensity I_2 with vector E perpendicular to this plane $\Delta = I_1/I_2$. During the experiment measurements were made of the values of I_1 and I_2 under various optical thicknesses of the medium $\tau = \varepsilon l$, where ε is the coefficient of weakening calculated per unit length and l is the geometric thickness of the scattering layer. From a correlation of experimental curves $I_1(\tau)$ and $I_2(\tau)$, a calculation was made for Δ and then, according to Formula (1), for P. The method described does not permit determination of the degree of ellipticity of scattered light polarization; however, it significantly reduces measurement errors

caused by the temporary instability of the media under investigation.

POLARIZATION OF LASER RADIATION REFLECTED BY FOG AND SMOKE

Results of the measurements of intensities of light reflected by fog and smoke ($\beta = 172^{\circ}$, $\phi = 90^{\circ}$) are shown respectively in Figures 2 and 3. The measured optical thicknesses of the layer of the scattering medium are presented along the X-axis and along the Y-axis: on the left is shown radiation intensity on a logarithmic scale in terms of laser radiation intensity and on the right is shown degree of polarization the scattered radiation with reversed sign. Figures 2 and 3 show that the patterns of the dependence of intensities I_1 and I_2 on τ observed in fog are also characteristic for smoke. Component I_2 (curve 2) in both media attains maximum at $\tau = 0.75$ and thereafter diminishes monotonically. The maximum for I_1 (curve 1) is not so clearly evident, and is displaced into the area of large optical thicknesses ($\tau = 1.2$). The conformity of the empirical curve 2 in the area $\tau \leq 1$ with the estimated curve 3 obtained in the approximation curve for single scattering shows that the maximum I_2 is created by a singly radiation scattering while the maximum is created by scattering of higher order. Since $I_1 < I_2$ is within the measured range of optical thicknesses, the degree of polarization of scattered radiation determined

by (1) is negative (curve 4).

It should be noted that the degree of polarization of the reflected radiation as early as $\tau \ll 1$ differs from the value of P of the radiation of the source, and is somewhat greater for smoke than for fog. Evidently the results obtained can be explained by the fact that radiation with linear polarization reflected from the medium is polarized elliptically. This assumption is in agreement with conclusions of the study [9] to the effect that for particles with $\rho \gg 0.7$-0.8 one can expect noticeable values for the degree of ellipticity of backward scattered radiation during linear polarization of incidence. With increase in τ the contribution of multiply scattered radiation grows (see curves 2 and 3). This leads to a reduction of the measured degree of the polarization of the reflected signal.

As shown by the experimental data in Figure 4, the dependence on τ of the degree of polarization P reflected radiation is approximatly represented by the linear function

$$P(\tau) = P_o - k\tau,$$

where P_o and k are empirical parameters. Preliminary investigations show that the sign of P_o and k is determined by the position of the polarization plane of the source relative to the scattering plane. A change in the angle ϕ by 90^o leads to a reversal of the sign of P_o and k (Figure 4 curves 1 and 2). The absolute magnitude of P_o and k depends

on the properties of the scattering media (curves 4 and 2) and to a lesser degree, on the angle of divergence of the radiation source (curves 2 and 3).

POLARIZATION OF LASER RADIATION
SCATTERED AT SMALL ANGLES

The dependence on τ of the degree of radiation polarization scattered forward at small angles ($\beta = 1^{\circ}30'$) is shown in Figure 5. Measurements were made in clouds for I_1 and for I_1 and I_2 separately and also for I_1+I_2. It is apparent that the curve calculated according to the formula for single scattering describes quite well the experimental data. The intensity of I_1 and the sum of I_1 and I_2 in fog within the limits of measurement errors coincide at $\tau \leqslant 12$ and in smoke with the same optical thicknesses I_1 greater than I_2 by an order of 2.5. Consequently, in the forward direction scattered radiation for both fog and smoke is polarized linearly in the plane coinciding with polarization plane of incident radiation.

The results obtained attest that during the distribution of narrow laser beams the theory of single scattering adequately describes not only the dependence of the intensity of scattering upon the light from the optical thickness [10], but also the polarizing properties of the scattering before the light, at least to optical thicknesses $\tau = 12$.

Figure 1. Optical Diagram of the Measurements:

β- Angle of scattering

V- Scattering area

l- Geometric thickness of the medium layer

d- Distance between the radiation detector 1 and the source 2

Figure 2. Components of intensivity I_1, I_2 and the degree of polarization of laser radiation reflected by fog: 1 - I_1, 2 - I_2, 3 - calculation of reflected radiation approximating single scattering, 4 - P (τ).

Figure 3. Components of intensivity I_1, I_2 and the degree of polarization of laser radiation reflected by smoke. 1-4 - see Fig. 2.

Figure 4. Degree of polarization of reflected radiation under various experimental conditions: 1-a = b', $\phi = 0^{\circ}$; 2-a = b', $\phi = 90^{\circ}$; 3-a - 40", $\phi = 90^{\circ}$ (1, 2, 3 - smoke); 4-a = b', $\phi = 90^{\circ}$ (fog).

Figure 5. Components of intensivity I_1 and I_2 forward scattered laser radiation under small angles: 1 - fog - I_1 (circles), (I_1+I_2) (triangles), 2 and 3 - smoke - I_1 (2), I_2 (3). Lines - calculation of approximation of single scattering.

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